Optimal Asset Distribution for Environmental Assessment and Forecasting Based on Observations, Adaptive Sampling, and Numerical Prediction

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LONG-TERM GOAL

The long-term goal is to enhance our understanding of coastal oceanography by means of applying simple dynamical theories to high-quality observations obtained in the field. My primary area of expertise is physical oceanography, but I also enjoy collaborating with biological, chemical, acoustical, and optical oceanographers to work on interdisciplinary problems. I collaborate frequently with numerical modelers to improve our predictive capabilities of Navy-relevant parameters in the littoral zone.

OBJECTIVES

The objective of this Multi-University Research Initiative (MURI) grant, subtitled, "The Adaptive Sampling and Prediction System (ASAP)" is to learn how to deploy, direct, and utilize autonomous vehicles [and other mobile sensing platforms] most efficiently to sample the ocean, assimilate the data into numerical models in real or near-real time, and predict future conditions with minimal error. The scientific goal is to close the heat budget for a control volume surrounding a three-dimensional coastal upwelling center, and identify via the magnitude of the terms the relative importance of the surface fluxes, boundary layer processes, alongshore advection, and mesoscale interactions in determining the temperature changes within the box.

APPROACH

The mobile assets for this project included 10 gliders (6 Slocum vehicles from WHOI and 4 Spray vehicles from SIO), 3 propeller-driven vehicles (DORADO from MBARI and 2 Odysseys from MIT), a research aircraft (NPS TWIN OTTER) and several support ships (SHANA RAE, POINT SUR, ZEPHYR, SPROUL, NEW HORIZON). Given these resources and the objectives above, a control volume (Figure 1) was selected for the 2006 experiment. The box, approximately 40 x 20 km, enclosed the upwelling center that is of central scientific interest. Six gliders were deployed along "racetracks" within the box and 4 were deployed as "rockers" oscillating back-and-forth along the boundaries, one on each end and two covering the offshore side. Using a combination of autonomous and human-activated control, the gliders were coordinated as a group to optimize the sampling coverage of the control volume in response to the ever-changing current conditions. A pair of bottom-

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14. ABSTRACT
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15. SUBJECT TERMS

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mounted acoustic Doppler current profilers (ADCPs) was also deployed along the southern boundary of the box to sample and report the internal wave environment in real time via a Seaweb underwater network.

The real-time observations were ingested into the NCOM, HOPS, and ROMS numerical ocean models each evening for predictive runs for the following day. Assets were then re-allocated to optimize sampling coverage and minimize model predictive error. See also annual report of the same name by Prof. Naomi Leonard of Princeton, for more detail on the coordinated control, adaptive sampling, and numerical prediction aspects of this program.

WORK COMPLETED

The field program for August 2006 was a great success (see last year's annual report for a complete description). This year the emphasis switched to analysis, synthesis, and publication of the results. A workshop was held in Woods Hole, MA during June 2008. The investigator also visited R. E. Davis at SIO for a few days to collaborate on the glilder/mooring comparisons and the heat flux problem. The PI's Effort during this evaluation period was on preparing a manuscript for publication which provides an overview of the oceanographic conditions during the experiment, as well as model/data comparisons between the three models (HOPS, ROMS, and NCOM) and the moored ADCPs. The manuscript is similar in tone and styly to our overview of the AOSN-II 2003 experiment [Ramp et al., 2009]. The second draft has been completed and is presently being circulated to the co-authors for final comments before submittal. We have additionally continued to work on glider/mooring comparisons in shallow water, particularly now comparing shear estimates from the moored and glider-mounted ADCPs.

RESULTS

One remarkable new result was the sub-mesoscale variability in the atmospheric forcing observed by the TWIN OTTER aircraft. MBARI Buoy M2, long the standard for local determinations of the surface wind stress, was often not representative of the local wind conditions around Point Año Nuevo. During poleward wind events, a local maximum resembling an expansion fan was observed to the north of the point. During equatorward events, there was a clear maximum in the wind stress directly off Año Nuevo, accompanied by weak winds in the "wind shadow" behind the Santa Cruz Mountains. This lead to a region of high positive wind stress curl, capable of driving local upwelling of the same order as coastal divergence. This feature may contribute to the "cold plume" that sometimes extends southward from Año Nuevo across the Monterey Bay.

The ADCP currents were dominated by poleward flow at both locations, despite the local coastal wind stress being mostly equatorward. The across-shelf scales were much smaller than the along-shelf scales. Model results and coastal sea level data suggest that the poleward flows were associated with free coastally-trapped waves with a period of 15 days and a wavelength of order 3500 km. None of the model now-casts picked up these waves, although a subsequent re-analysis using the NCOM model with HYCOM forcing showed a dramatic increase in predictive skill. This demonstrates the importance of the boundary conditions when forecasting small domains in the coastal ocean.

IMPACT/APPLICATION

All recent Navy METOC publications indicate that autonomous vehicles are the way of the future in battlespace environmental assessment. The Naval Oceanographic Office has already initiated procurement of large numbers of gliders and significant numbers of propeller-driven vehicles. Experiments such as ASAP will help the Navy to learn how to utilize these vehicles most effectively, to maximize the information returned, and to assimilate the data into numerical models for environmental prediction. It has been demonstrated that assimilation of glider data into Navy models improves nowcasts, hindcasts, and 1.0-1.5 d forecasts [Shulman et al., 2009].

TRANSITIONS

The virtual control room (COOP) has been used to support several subsequent Navy field experiments including the MB08 "Oktoberfest" experiment. Collaborative control of fleets of autonomous vehicles is being considered for use in the national Integrated Ocean Observing System (IOOS) as it minimizes daily human-in-the-loop interactions and reduces costs for long-term ocean monitoring.

RELATED PROJECTS

See ONR Annual Report by Naomi Leonard (Princeton)
See ONR Annual Report by Jim Bellingham (MBARI)
Persistent Litoral Undersea Surveilance network (PLUSnet)
Assessing the Effects of Submesoscale Ocean Parameterizations (AESOP)
Layered Organization of the Coastal Ocean (LOCO)
NRL BIOSPACE Experiment summer 2008
MB08 "Oktoberfest" ocean color and harmful algal bloom experiment
San Francisco Bayweb I and II, spring and summer 2009, San Francisco Bay - Acoustic networking of ocean sensors in a high-current, high-noise environment.

PUBLICATIONS

Ramp, S. R., 2009: "The Adaptive Sampling and Prediction System" ONR Unmanned Undersea Systems Review, Orlando, FL, February 2009.

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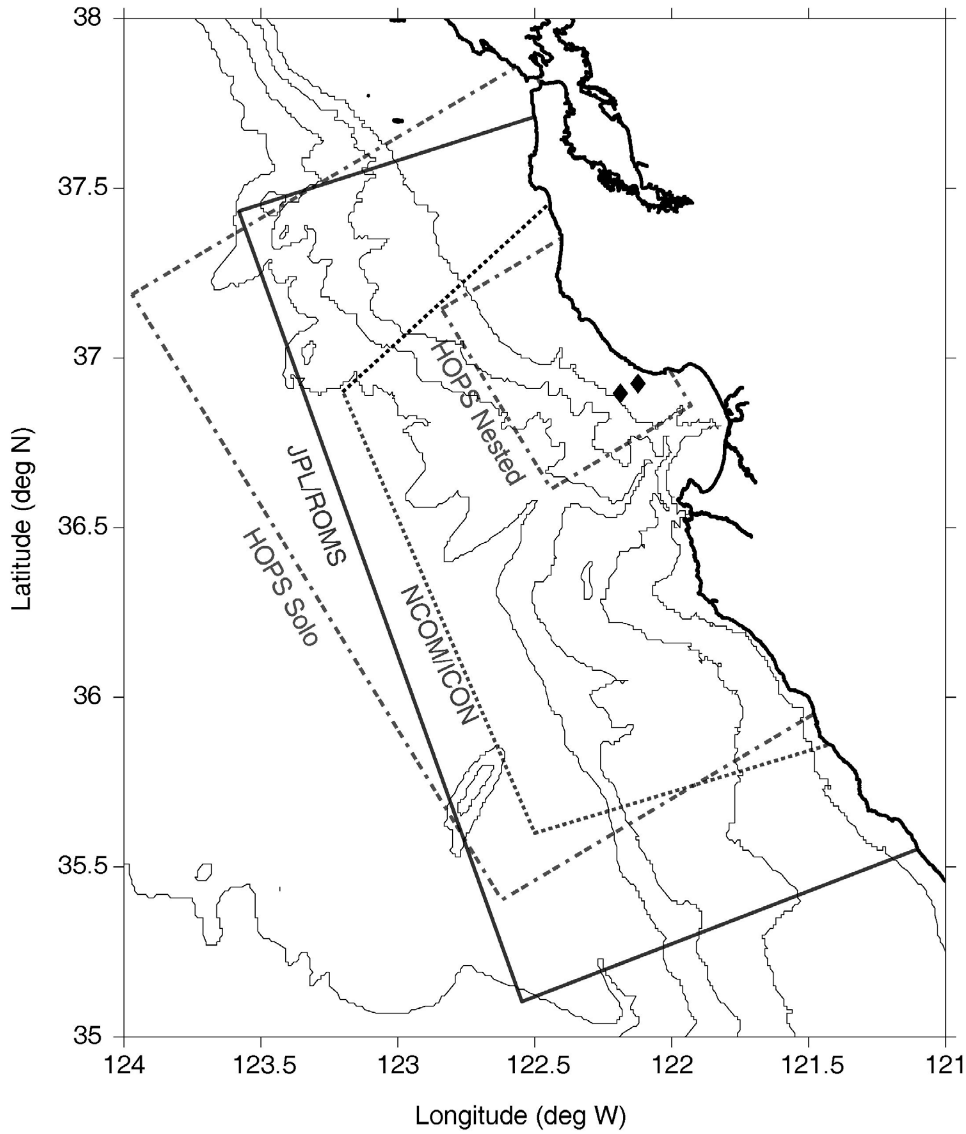

Figure 1. Adaptive Sampling and Prediction Experiment location showing the moorings (black diamonds), and the various model domains.

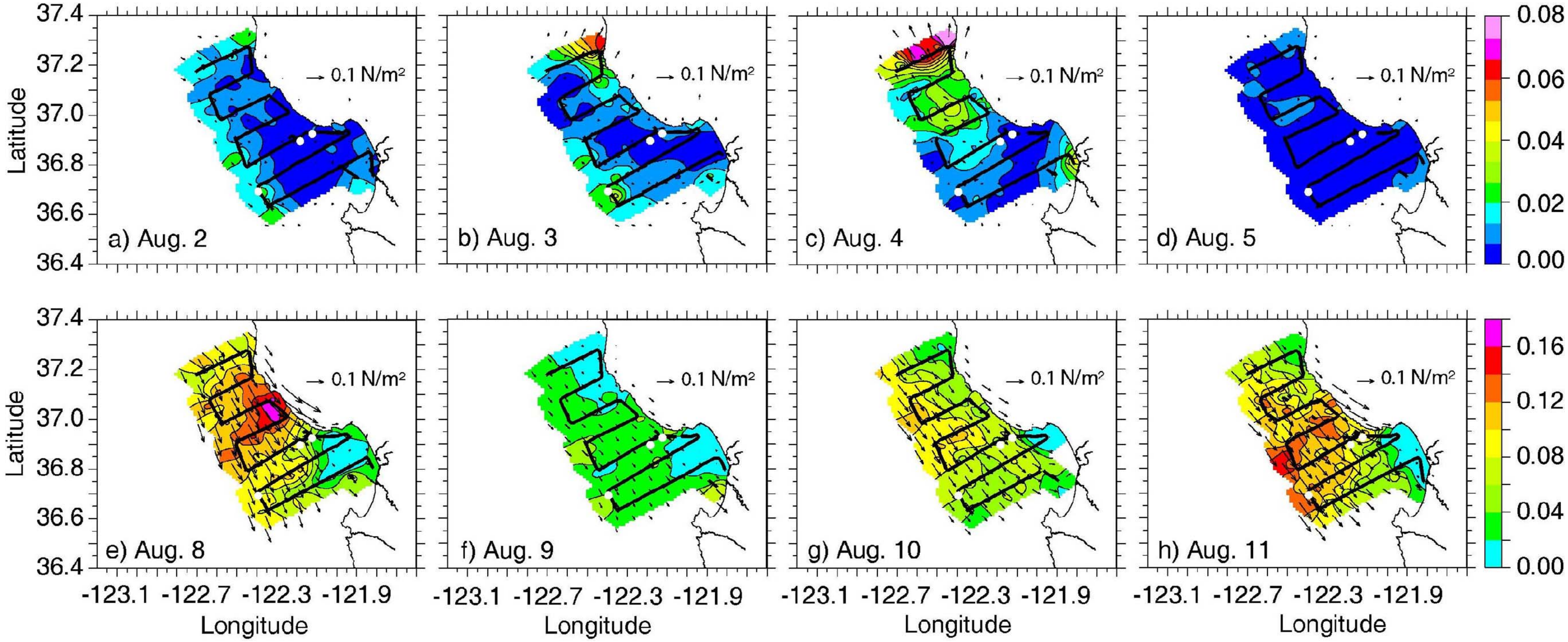

Figure 2. Time series of the aircraft-observed surface wind stress during (a-d) the August 2-5 wind relaxation event and (e-h) the August 8-11 upwelling favorable event.

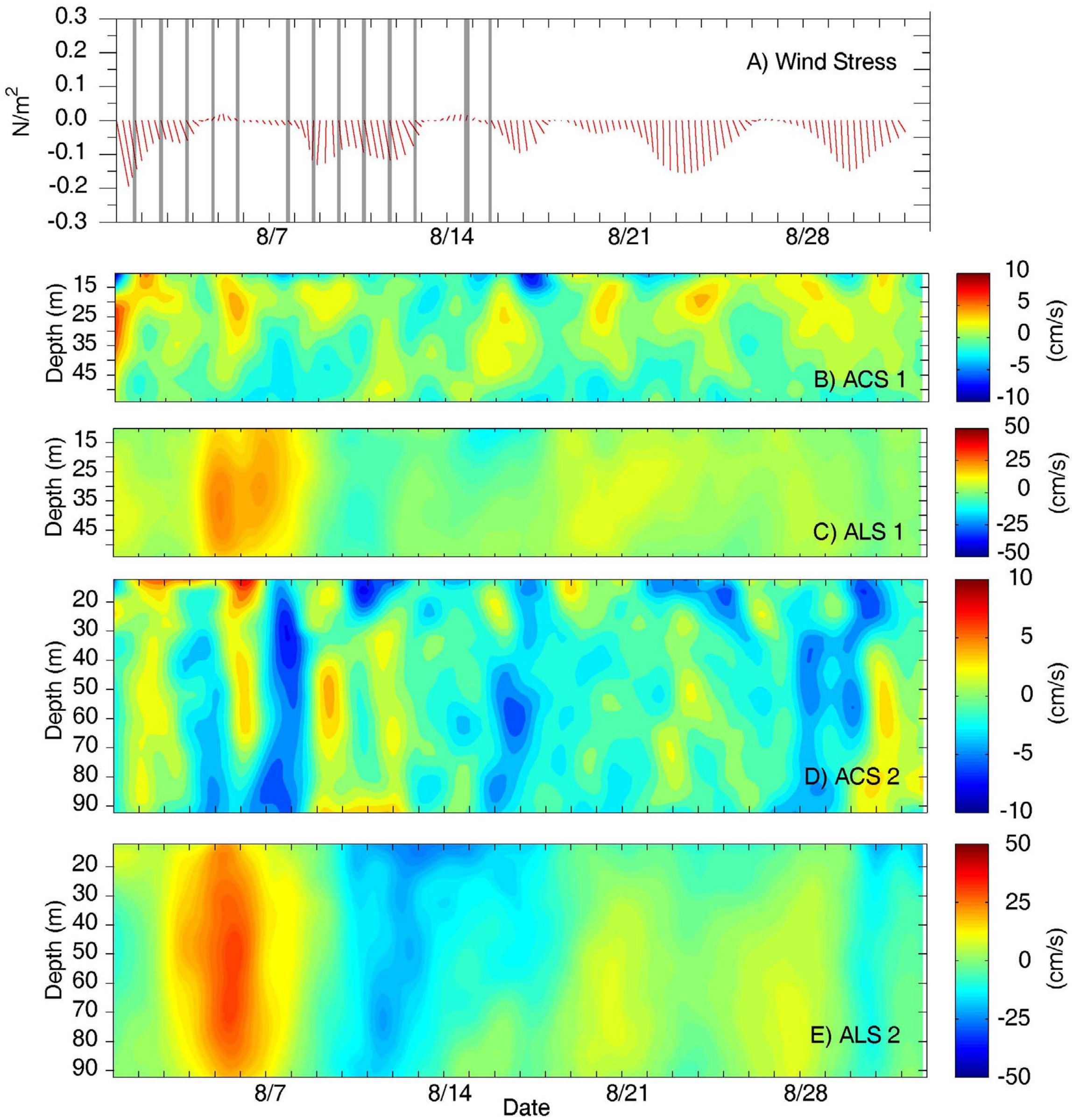

Figure 3. Time series of a) wind stress from MBARI Buoy M2, b) across-shore current at ADCP 1, c) alongshore current at ADCP 1, d) across-shore current at ADCP 2, and e) alongshore current at ADCP 2. The scale of the y-axis is the same for both ADCPs, with the difference in plot height reflecting the difference in water depth. The velocity scales are different for the across- and alongshore components to better illustrate the much smaller across-shore flow. The vertical gray bars on the wind stress plot indicate the time of the TWIN OTTER over-flights. A positive sign indicates poleward and onshore flow.